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# EFFECT OF SOIL AND COVER CONDITIONS ON SOIL-WATER RELATIONSHIPS

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## INTRODUCTION

PEOPLE WHO MAKE flood-control surveys for the U. S. Department of Agriculture are concerned with the physical condition of the soils in the watersheds. The condition of the soil determines how fast water moves into and through the soil, and how much water is held in storage. The condition of the soil has a great influence on stream flow, erosion, floods and water supply.

So before land-management programs can be planned to remedy flood problems and conserve water, it is essential to know what factors affect the condition of the soil, and how they effect it. Some of the most important factors are the vegetative cover, the natural drainage, and the kind and intensity of land use.

Land use is especially important. We know that man can--to a great extent--change the physical condition of the upper layers of the soil by the way he uses the land and controls the vegetation on it. He can change the rate at

which water flows into and through the soil; he can change the soil's capacity to store water.

During a flood-control survey of the Allegheny River watershed in Pennsylvania and New York, the authors made a study of representative soils and the factors that affect them. This is a report about that study. The conclusions in it are only tentative; more intensive sampling is needed before firm conclusions can be drawn. But until more conclusive studies can be made, this report is offered as a guide to others who are concerned with studies of the effect of vegetation and land use on soil-water relationships.

## PURPOSE AND SCOPE

THE AUTHORS TRIED in this study to determine the rates of water movement and the storage capacities of the soil profiles found in the Allegheny River watershed. They tried to define the effects of soil, cover, and land use on these water conditions. Information about these effects would be useful in planning a program to reduce floods in the watershed by storing more water in the soil.

At the same time, they tried to find some correlations between such physical soil characteristics as organic content and volume weight and the movement and storage of water in the soil. Such correlations would make it possible, in future flood-control surveys, to use fairly simple methods for determining soil-water relationships.

To measure the movement and storage of water in the soil, it was first necessary to work out numerical values for four factors:

1. Percolation rate.--The quantity of water, in inches, that passes a given point in the soil profile in a given time.

2. Transmission capacity.--The percentage of saturation attained at the time water is first transmitted through the soil. This was needed for computing transmission rates.

3. Transmission rate:--The vertical distance, in inches, that water travels through the soil in a given time (generally 1 hour).

4. Detention storage capacity.--The amount of water held temporarily in storage by the soil. This is water storage above field capacity; it is subject to loss through gravity. It is expressed as a percentage by volume.

5. Retention storage capacity.--"The amount of water held in the soil after the excess of gravitational water has drained away and the rate of downward movement of water has materially ceased" (12).[1] Also called field capacity. It is expressed as a percentage by volume. Saturation capacity minus detention storage capacity equals retention storage capacity.

The scope and intensity of the study were limited to the following considerations: (1) The field work had to be completed in 6 months to meet the time schedule of the Allegheny flood-control survey. (2) Within this time limit, soil-water relationships had to be determined for all of the extensive soil-cover complexes found in the watershed.

Published reports and other current investigations contain considerable information about such soil-water problems. In general, however, this information was not adaptable to the numerous soil-cover complexes found in the Allegheny River watershed.

# METHODS

## Selection Of Soil-Cover-Use Complexes

A SOIL-COVER-USE COMPLEX is a combination of the soil conditions, the vegetative cover, and the land use that affect the movement and storage of water in the soil. These complexes were too numerous for individual sampling; so they were grouped. The grouping was made on the basis of (1) features that could be easily recognized during a field survey and (2) expected differences in soil-water relationships between the complexes.

[1] Numbers in parentheses refer to Literature Cited, page 31.

Table 1.--Number of field plots sampled in medium-texture soils, by soil-cover complexes

FOREST LAND

| Cover | Drainage class | | | |
|---|---|---|---|---|
| | Well-drained, deep | Well-drained, shallow | Imperfectly drained | Poorly drained |
| Previously forested, ungrazed and unburned: | | | | |
| Coarse and medium mull | -- | 1 | 1 | 2 |
| Fine mull | 4 | -- | 2 | -- |
| Firm mull | 1 | -- | -- | -- |
| Greasy mor | 1 | 1 | 2 | 1 |
| Other mors | 4 | -- | 2 | 1 |
| Previously open, ungrazed and unburned: | | | | |
| Natural restocking | | | | |
| Coarse and medium mull | 1 | -- | 1 | 1 |
| Greasy mor | 1 | -- | -- | -- |
| Plantation | | | | |
| Coarse and medium mull | -- | -- | -- | 1 |
| Fine mull | -- | 1 | -- | -- |
| Burned | | | | |
| Other mors | 1 | -- | -- | -- |
| Grazed | | | | |
| Coarse and medium mull | 2 | 1 | 2 | -- |
| Fine mull | -- | -- | 1 | -- |
| Firm mull | -- | 2 | 2 | 1 |
| Other mors | 2 | -- | 1 | -- |
| OPEN LAND | | | | |
| Row crops | 1 | -- | 3 | -- |
| Grain crops | -- | -- | 2 | 1 |
| Hay | 2 | -- | -- | 1 |
| Good pasture | 1 | -- | 2 | -- |
| Poor pasture | 1 | 1 | 5 | 1 |
| Abandoned pasture | -- | -- | 2 | 2 |

Two major land-use groups were recognized, forest land and open land. Forest land was further classified according to humus type, past history, presence of grazing, and occurrence of fires. Open land was further classified according to type of cover and use of the surface, i.e., pasture, row crops, hay, grain, and idle or abandoned land.

Two soil-depth classifications and two texture classifications were used. Soils more than 24 inches deep to


Figure 1.--The four areas sampled were considered representative of the watershed.

bedrock were classified as deep soils and those less than 24 inches as shallow soils. Soil texture was classified as either light or medium in accordance with standard soil-survey procedures.[2]

Soils were also classified--on the basis of internal drainage--as well-drained, imperfectly drained, or poorly drained.

The soil-cover-use complexes that were sampled in the field are listed in table 1, together with the number of plots studied in each complex.

## Field Procedure

Sampling was concentrated in four gaged subwatersheds as follows: (1) Allegheny River above Red House, N. Y., (2) Clarion River above Cooksburg, Pa., (3) Conemaugh River above Seward, Pa., and (4) French Creek above Utica, Pa. (fig. 1). These were selected as being representative of the soil, topography, and land-use conditions in the entire Allegheny watershed.

Plots were located at regular intervals along selected roads to obtain a representative sample of the soil-cover complexes. (Bias resulting from sampling along roads should be small, since the data sought are soil-moisture values for different complexes rather than distribution of complexes.) At each stop the plot was established 3 chains in from the type boundary at the point nearest the road. Exact location of the plot was made on a mechanical basis.

Once the plot was located, the first step was to tabulate all the cover data needed for classifying the complexes. Next, a trench about 4 feet long and 1 foot wide was dug down into the mineral horizon. The profile characteristics were recorded and the depths of the different

[2] Determination of soil texture was made in the A horizon. Soils that fell in the range between fine sandy loam and fine gravel were classified as light-texture soils. Those in the range from silt loam to very fine sandy loam were classified as medium texture. The majority of the soils in the Allegheny watershed are loams and silt loams of residual origin, and they fall in the medium-texture classification. Most of the light soils in the watershed are found in the heavy end of the light-texture range, that is fine sandy loam.

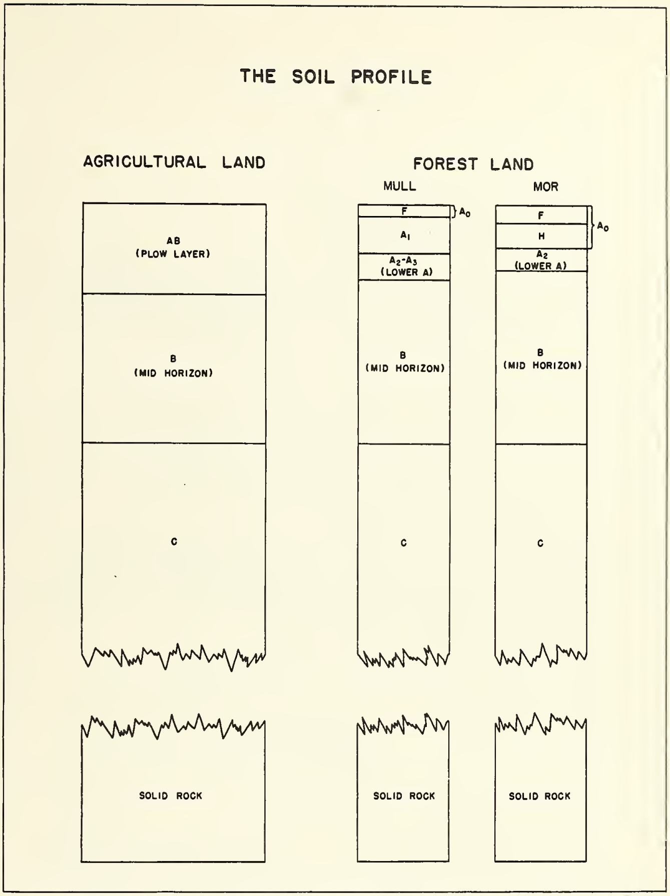


Figure 2.--The soil horizons used in this study. The term 'mid-horizon' is used to designate the B horizon of mature profiles and the comparable profile depth in an AC or immature profile. In the immature profile this 'mid-horizon' is the upper part of the C horizon and is found in the same relative position as the B horizon in soils that have an ABC profile.

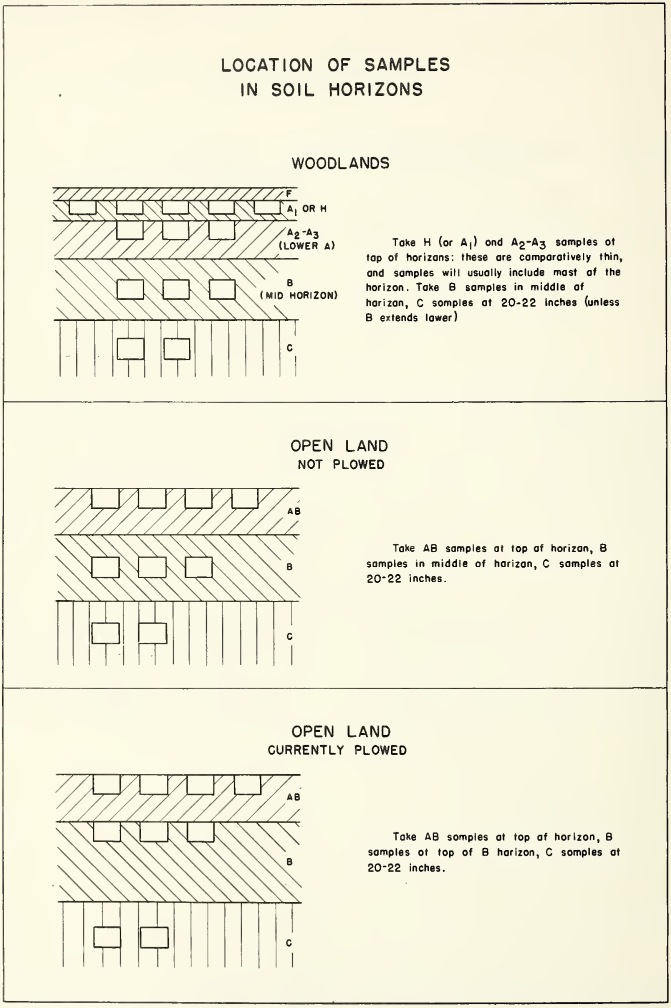


Figure 3.--Distribution of samples within the various soil horizons.

horizons were measured. The soil horizons used in this study are illustrated in figure 2. A more detailed discussion of the soil horizons is found in the appendix.

Samples were taken in each horizon. The number of samples and their locations within the horizons are shown in figure 3. In forest plots and in open-land plots not recently plowed, the mid-horizon samples were taken from the middle of the horizon. In open-land plots that had been plowed during the last two seasons, the samples were taken near the top of the mid-horizon.[3]

The methods used in field sampling and laboratory work were essentially those of Nelson and Baver, Bendixen and Slater, and others. The soil cores were collected in thin-walled copper cylinders, 3 inches in diameter. Two sizes were used: 2.158 inches long for sampling horizons 2 inches or more thick, and 0.863 inches long for sampling thin horizons (mainly H, $A_1$, or $A_2$ in forest plots). These cylinders were fitted into a steel cutting head that was mounted on a metal shaft. The cylinders were driven into the soil by pounding the top of the shaft with a hard rubber mallet (fig. 4).

Accuracy of the sampling was determined by statistical analysis of the soil-water values. For details, see appendix.

## Laboratory Procedure

The soil samples were tested to get the following values for each sample:

1. Amount of water present in the sample (field moisture content.)
2. Transmission rate.
3. Transmission capacity (amount of water held in the sam-

[3]THE REASON FOR THIS LIMITED SAMPLING THROUGHOUT THE MID-HORIZON IN PLOWED AREAS INDICATED THAT PERCOLATION RATES IN THE UPPER MID-HORIZON WERE AS LOW AS OR LOWER THAN IN THE MIDDLE OF THE SAME HORIZON BECAUSE A PLOW SOLE FORMED A BOTTLENECK JUST BELOW THE PLOW LAYER. ON THE OTHER HAND, IN UNPLOWED SOILS PERCOLATION RATES SEEM TO DECREASE GRADUALLY FROM THE SURFACE DOWN.

Figure 4.--Method of collecting a soil core. A, after vegetation is cleared away (this is an A-horizon sample), the sampling tool is driven in. B, the soil core is examined to make sure it is a good sample. C, the copper cylinder is removed from the cutting head and the excess soil is trimmed off. D, the sample is sealed tightly to prevent loss of moisture.

ple at the end of transmission-rate determination).

4. Percolation rate.

5. Detention-storage capacity.

6. Retention-storage capacity.

7. Volume weight.

8. Organic content of sample.

The equipment used in the laboratory tests was portable. It could be packed up and moved from one temporary set-up to another without inconvenience. Field set-ups could be made wherever a small room was available. One such set-up was made in each subwatershed sampled.

All of the values determined from the soil samples were obtained in the field laboratories except organic-matter content. For this measurement the samples were taken to Pennsylvania State College.

The first values obtained were the fresh weights of the samples. These were needed later for determining field moisture content.

A transmission run was made to obtain transmission rate and transmission capacity. This consisted of applying water to the surface of the soil sample as rapidly as the sample could absorb it. The elapsed time from the moment of initial application until the first drop appeared on the bottom of the sample was recorded. The transmission rate in inches per hour was computed from the time interval and the depth of the soil sample.

The amount of water taken up by the sample during the transmission-rate determination was recorded. To calculate transmission capacity, this volume was added to the moisture already present in the sample and the total was expressed as a percentage of the water held at saturation.

The samples were then saturated by continuing to apply water directly onto the upper surface until the dis-

charge at the bottom became constant.[4] Percolation rate was determined by measuring the amount of outflow at the bottom of the saturated sample (fig. 5). This was expressed in inches of water per hour.

Saturated weights were then obtained for use in determining total moisture-storage capacity.

The next step was to determine detention-storage capacity. The soil samples were drained on a tension table at 60 centimeters tension (pF 1.78) for 12 hours to remove the free gravitational water (fig. 6). We realize that detention storage or field capacity does not correspond to the same water tension in all soils; but it was necessary to use a standard tension for laboratory determinations.

The samples were then placed in an oven and dried to constant weight at 105° C. to determine the retention-storage capacity and the volume weight. The former is equal to the difference between sample weight immediately before and after oven-drying. The latter is the relationship between the volume of a soil and its dry weight. It has been called the apparent specific-gravity of a soil and is determined by dividing the oven-dry weight of a soil sample in grams by its volume in cubic centimeters. All storage capacities were expressed on a volume basis.

The amount of organic material in the samples was determined by the dichromate and loss-on-ignition methods.

## ANALYSIS

THE ANALYSIS WAS CARRIED out in two steps. First, similar soil-cover complexes were combined. Second, individual soil-cover complexes were analyzed and the relationships between the components of the soil-cover complex and the soil-water values were determined.

[4] Samples that wet slowly (as evidenced during the transmission run) can be brought near the saturation point in a fairly short time by placing them in a pan containing enough water to rise above the bottom of the samples. This method would probably be necessary when very sandy soils are sampled because they could not be kept saturated as long as they had free drainage below.

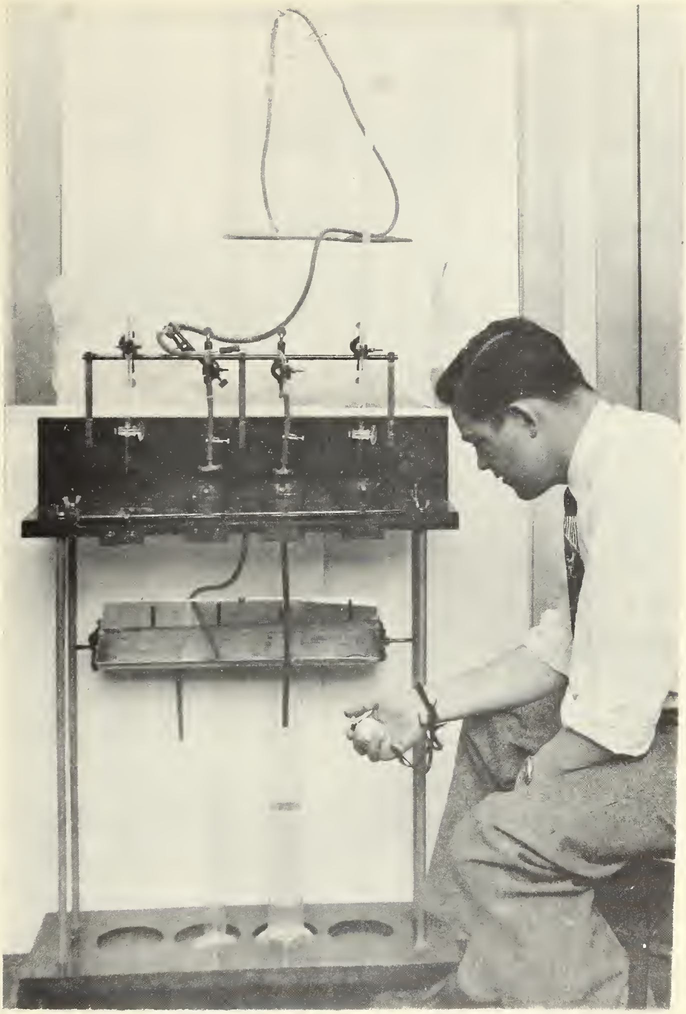

Figure 5.--Determining the percolation rate.

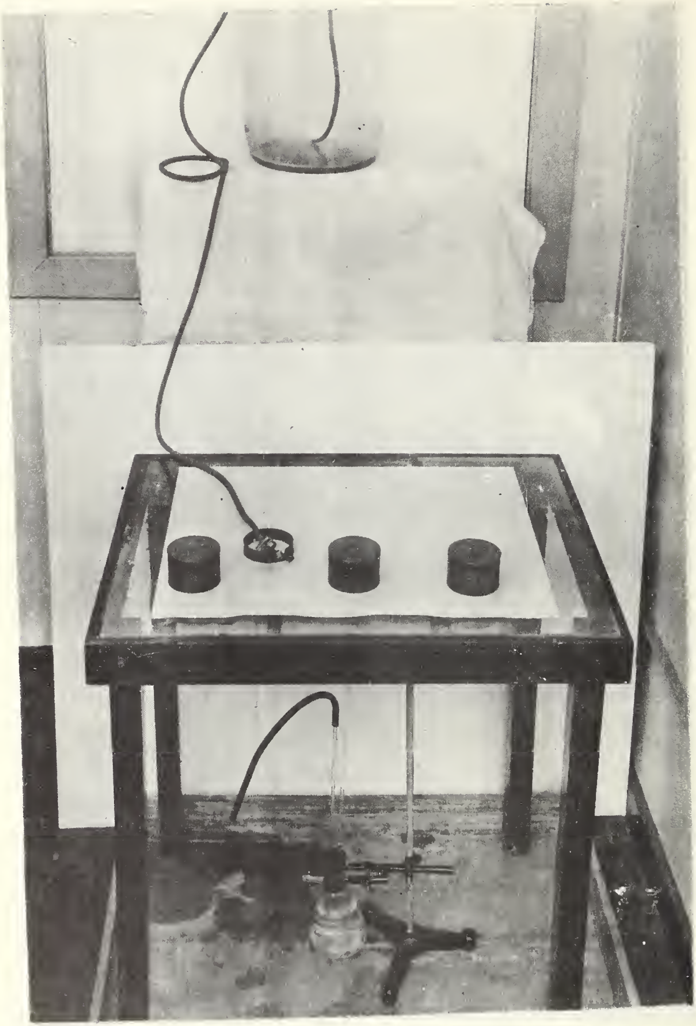

Figure 6.--Tension tables used for determining detention-storage capacity.

Following the compilations, an inspection of the data indicated that certain reductions could be made in the number of soil-cover complexes. The greatest reduction was made by eliminating the light-texture soil group from detailed analysis. These soils are found on only a small percentage of the watershed area and few field plots fell in this soil-texture group. As a result the original number of complexes was reduced by half. A discussion of soil-water values in light-texture soils is included in the appendix.

The complexes were reduced still further by including with the ungrazed forest plots the single burned forest plot and the few plots in previously open land that is now covered with either natural forest or plantations. Average soil-water values for these plots fell close to the plot averages for the complex "previously forested-ungrazed-unburned forest."

The complexes were grouped on the basis of the most important and most variable soil-water value, namely percolation rate. Following this grouping, average values were obtained for detention storage, retention storage, organic content, and volume weight for each significant percolation class. The results of this analysis are shown in tables 2 and 3.

## Percolation Rates

Percolation rates were analyzed in the following manner:

1. On the basis of inspection, the rates were grouped by soil-cover complexes and horizons believed to be significantly different in their percolation characteristics.

2. The groups were compared statistically by Fisher's "t-test" and, basing significance on the 5-percent level, a number of combinations were made. When the "t" is too large to be random, this test proves the existence of a real difference while the fact that it is smaller does not prove homogeneity. Homogeneity is assumed when classes are combined.

3. Classes represented by single plots were combined on the basis of reasonable similarity or were left ungrouped.

Table 2.--Soil-water relationships and physical soil characteristics, by horizons and soil-cover complexes, for forest land

| Horizon | Humus type | Profile drainage[1] | Land use | Plots | Percolation rate[2] | Detention storage | Retention storage | Organic content | Volume weight |
|---|---|---|---|---|---|---|---|---|---|
| | | Class | | Number | Inches per hour | Percent by volume | Percent by volume | Percent by weight | |
| H | Mors | 1-2-3-4 | Ungrazed | 9 | 236.0 | 33.8 | 37.8 | 40.8 | 0.31 |
| $A_1$ | Firm mull | 1-2-3-4 | Ungrazed | 1 | 62.7 | 27.3 | 32.6 | 8.4 | .87 |
| | Other mulls | 1-2-3-4 | Ungrazed | 12 | 132.0 | 23.4 | 41.1 | 24.7 | .51 |
| | Mulls | 1-2-3-4 | Grazed | 9 | 30.2 | 12.6 | 41.4 | 16.9 | .92 |
| Lower A | Firm mull | 1-2-3 | Ungrazed | 1 | 7.8 | 14.5 | 31.7 | 2.9 | 1.19 |
| | Other mulls and mors | 1-2-3 | Ungrazed | 21 | 17.0 | 14.8 | 36.8 | 6.4 | 1.01 |
| | | 4 | Ungrazed | 5 | 10.9 | 10.8 | 40.4 | 5.4 | 1.05 |
| | Mulls and mors | 1-2-3 | Grazed | 7 | 13.1 | 13.7 | 38.3 | 5.9 | 1.07 |
| | | 4 | Grazed | 1 | 3.6 | 5.1 | 40.8 | 4.1 | 1.37 |
| Mid-horizon | All humus types | 1-2-3 | Grazed & ungrazed | 32 | 4.9 | 10.6 | 36.3 | 2.3 | 1.29 |
| | | 4 | | 7 | 2.7 | 6.0 | 37.8 | 1.5 | 1.42 |
| C | All humus types | 1 | Grazed & ungrazed | 10 | 2.0 | 10.7 | 34.8 | 1.0 | 1.39 |
| | | 3-4 | | 15 | .4 | 5.9 | 34.9 | .7 | 1.56 |

[1] 1, Well-drained deep; 2, Well-drained shallow; 3, Imperfectly drained; 4, Poorly drained.

[2] Relative soil core rates.

Table 3.--Soil-water relationships and physical soil characteristics, by horizons and soil-cover complexes, for open land

| Horizon | Profile drainage | Land use | Plots | Percolation rates | Detention storage | Retention storage | Organic content | Volume weight |
|---|---|---|---|---|---|---|---|---|
| | Class | | Number | Inches per hour | Percent by volume | Percent by volume | Percent by weight | |
| AB or AC | 1-2-3 | Row crop | 2 | 6.6 | 10.3 | 35.5 | 4.9 | 1.26 |
| | 4 | Row crop | 1 | 2.9 | 8.4 | 51.0 | 5.0 | 1.14 |
| | 1-2-3-4 | Close-growing crops | 6 | 21.7 | 12.7 | 38.3 | 5.0 | 1.11 |
| | 1-2-3 | Hay | 6 | 21.7 | 12.7 | 38.3 | 5.0 | 1.11 |
| | 4 | Hay | 2 | 7.7 | 9.2 | 42.7 | 6.8 | 1.05 |
| | 1-2-3 | Good pasture | 3 | 18.5 | 7.7 | 43.1 | 6.0 | 1.18 |
| | 1-2-3 | Poor pasture | 5 | 12.8 | 11.0 | 38.3 | 5.5 | 1.19 |
| | 4 | Poor pasture | 1 | 2.5 | 4.7 | 50.5 | 8.2 | 1.21 |
| | 1-2-3-4 | Abandoned pasture | 6 | 12.8 | 11.0 | 38.3 | 5.5 | 1.19 |
| Mid-horizon | 1-2-3 | All open-land use classes | 16 | 4.4 | 7.7 | 37.7 | 2.2 | 1.37 |
| | 4 | | 6 | .7 | 5.8 | 36.3 | .9 | 1.46 |
| C | 1 | All open-land use classes | 2 | 2.3 | 9.8 | 38.2 | 1.0 | 1.35 |
| | 3-4 | | 9 | .7 | 5.3 | 37.0 | .5 | 1.54 |

The rates obtained are relative; they must be adjusted to show actual field percolation.[5] It would be impossible to measure field rates on cores in a laboratory. In their relative form, however, they show the effect of land-management practices on water movement. Along with storage capacities they suggest how man can modify the soil to increase the rate of infiltration and the amount of water stored in the ground.

In using these relative rates it must be kept in mind that soil-water data are extremely variable and that many of the complexes shown were not adequately sampled. The standard errors of the mean, discussed in the appendix, are a measure of the adequacy of the sampling. An unmeasured source of error exists in that it was not possible to determine the effect of large roots on the rate of water movement. This could not be measured through the use of soil cores. Thus it remains a source of possible error in comparing percolation rates from forested and nonforested areas; that is, the soil-sample rates obtained for forest soils may be lower in comparison with actual field rates than the soil-sample rates for agricultural soils.

The results of the percolation analysis are discussed below. For woodlands, the effects of different forest types and past history (whether forested or open), though undoubtedly important, were not adequately sampled because sufficient samples were not available. Most of the forest areas sampled supported Allegheny hardwoods, and had always been forested.

## Effect of cover and use

Woodland complexes.--Humus type was selected as the basic indicator of cover conditions in the analysis of woodland soil-cover complexes. This selection was made to find out if soil-water values within the humus layer varied by humus types. It also permitted us to determine if these differences were reflected in different percolation and storage values in lower mineral horizons.

[5]RATES FOR A GIVEN HORIZON OF THE PROFILE OF A COMPLEX ARE RELATIVE TO THE RATES FOR OTHER HORIZONS IN THAT COMPLEX AND TO THE SAME HORIZON IN OTHER COMPLEXES.

Five humus types were recognized; they are listed in table 1. The analysis of laboratory rates within the $A_1$ layer of mulls and the H layer of mors in ungrazed woods showed that only three humus types were significantly different: mor, including all the subdivisions listed by Heiberg and Chandler (5); firm mull, inadequately sampled but kept separate because of obvious physical differences; and other mulls, including coarse, medium, and fine mulls.

The percolation rates in the ungrazed forest, in both the $A_1$ layer of "other" mulls and the H layer of mors, are so high that rainfall intensities should seldom exceed them. The laboratory rates of percolation in the H layer of ungrazed forest mors were not so accurate as the rates obtained for the other horizons. There are two reasons for this: The percolation rates were so high that it was not possible to apply water on the samples fast enough; and it was difficult to take undisturbed samples in this horizon.

Percolation rates in the lower A horizon of mors, when compared to the rates in the lower A of the mulls, showed no significant differences. The high organic content and relatively weak leaching in the lower A of the mors of the gray-brown podzolic soils in this region account for this rather surprising condition. The typical mor humus of these soils is intermediate in character between mor and fine mull. So the rates for the lower A and H layers do not represent a true mor. This is obvious in respect to organic content, which for the H layer is less than 50 percent by weight.[6] The organic content of a true H layer would probably run between 75 and 95 percent.

Grazing of woodland reduced the percolation rate in the humus and this effect extends through the lower A horizon. Three intensities of grazing were recognized but because of inadequate sampling in any one class they were combined in the analysis. The middle or "moderate" grazing-damage condition is most heavily represented.

Other factors that influence soil-water relationships are density and stand age. These two conditions were re-

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[6] ANOTHER INFLUENCE THAT ENTERED HERE WAS THE FACT THAT THE HORIZONS WERE OFTEN SO THIN AND IRREGULAR THAT MANY SAMPLES INCLUDED SOME LOWER A HORIZON MATERIAL. THIS, BEING LARGELY MINERAL SOIL GREATLY REDUCED THE ORGANIC CONTENT OF THE SAMPLE.

corded for all plots and their influence was determined by analyzing the percolation rates. Within any one significant humus group, there were no significant differences in humus percolation rates between stands differing in age or density. Within the humus layer the effects of density and age are reflected in differences in humus type and depth.

The authors tried to determine if stand age and crown density had an effect on the percolation rates in the horizons below the humus. The results were inconclusive because of the small number of samples available. The difficulties involved in making such a comparison are tremendous. Indications are that in the profile below the humus layer differences due to stocking and age develop slowly. A difference in present age may or may not be reflected in differences in soil-water relationships. Since stand histories are unknown, particularly details of past cuttings, a valid comparison is impossible.

Open-land complexes.--The five soil-cover complexes left in the open-land soil group were reduced in the detailed analysis to four.

In the cultivated soils the effects of cover and use are confined to the plow layer. The data obtained indicated that these factors do not influence the soil-water relationships below this horizon.

The A-horizon rates in close-growing grain and hay land were similar; so the two complexes were combined. Row crops, which included all clean-tilled crops such as corn, potatoes, beans, and the like, were a significant class. Good pasture differed significantly from poor pasture in A-horizon percolation rates.

In this study the criterion determining pasture condition was ground-cover density of palatable and nutritious grasses. It is difficult to classify pasture into adequate hydrologic-condition classes since we have no clear-cut definition of what conditions are most influential. Agricultural agencies have generally classified pasture on the basis of its productive capacity in pounds of beef or milk. Such a classification is not adequate for hydrologic analysis.

In flood-control surveys there is need for a pasture classification that indicates soil-water relationships. Such a classification should be related to both ground-cover

density and intensity of grazing. Alderfer and Robinson (1) found that detention-storage capacity varied directly with percentage of ground cover and inversely with intensity of grazing. There were indications that the latter is the more important. To some extent the two conditions are directly correlated.

The percolation rates for poor and abandoned pasture were similar; so they were combined. It is logical to believe, however, that abandoned pastures that have grown up to grass, weeds, and brush may have better water relationships than any other kinds of open land. It so happened that the abandoned pastures sampled were abandoned because of erosion, and the plant cover had not yet built up to a point where improvement in soil structure could be expected.

Woodland and open-land complexes.--The average percolation rate in the mid-horizon of well-drained forest profiles was only slightly greater than that in the mid-horizon of open-land soils. The difference was not significant statistically. In poorly drained profiles the mid-horizon percolation rate for the forested soils was significantly higher than the rate for the open-land soils.

The percolation rates in the mid-horizon of the AC (immature) profile soils did not differ from mid-horizon rates in the ABC (mature) profile soils.

Cover and use did not affect the percolation rates in the C horizon (at 20-22 inches from the surface) of the medium-texture soils sampled. At least no difference was detected in this study. Apparently, few tree roots penetrate this horizon. Their influence is probably greater directly beneath the tree bole where we were not able to collect samples.

## Effect of drainage

Soil drainage conditions were analyzed on the basis of four drainage classes:

1. Well-drained deep--all unmottled soils more than 24 in-

ches deep to bedrock or an inhibiting layer.[7]

2. Well-drained shallow--all unmottled soils without an inhibiting layer but less than 24 inches deep to bedrock.

3. Imperfectly drained--soils that exhibit mottling or an inhibiting layer between depths of 8 and 24 inches.

4. Poorly drained--soils that exhibit mottling or an inhibiting layer above 8 inches in depth but are not permanently wet.

Percolation rates on both shallow and deep soil samples of the same drainage classes were similar; so the two were combined.

Woodland complexes.--Percolation rates in the humus were the same in all profile-drainage classifications. In the lower A layer, poorly drained soils had lower percolation rates than well-drained and imperfectly drained soils. This relationship is also true in the mid-horizon. In the C horizon, at 20+ inches the poorly and imperfectly drained soils had the same percolation rates. These rates, however, were lower than those in the well-drained soils.

Open-land complexes.--Percolation in the surface layer of agricultural soils varies at times with the drainage classification of the profile. At times the inhibiting layer was found close enough to the surface to influence the percolation rate of the sample. More often it was not. Its occurrence appeared to be mostly a matter of chance. Within the mid-horizons and C horizons in open-land soils the effects of drainage conditions were comparable to those in forest soils.

## Detention Storage

Average values were computed for detention storage, and these were grouped by the complexes that had significantly different percolation rates. They are shown in tables 2 and 3.

[7] POOR INTERNAL DRAINAGE RESULTS FROM THE PRESENCE OF AN INHIBITING LAYER IN THE PROFILE. LOCATION OF THIS LAYER DETERMINES THE DRAINAGE CLASSIFICATION OF THE PROFILE.

The amount of water held temporarily in the soil depends on the amount and nature of the available detention pore space. Other things being equal, the coarser the soil texture, the higher the organic content; and the greater the biological activity, the greater the detention-storage capacity. The nature of this capacity is variable. The storage space consists of holes and channels made by mice, worms, and decayed roots. It consists also of those spaces between the soil particles or soil aggregates that are so large that absorption and film forces cannot retain all the water in them against the pull of gravity.

The effect of soil-cover complex on detention pore space is similar to the effect of soil-cover complex on percolation rate. In general, soil and cover conditions that tend to increase the percolation rate also tend to increase the volume of detention storage.

Soil physicists generally agree that all of the temporary pore space is not utilized by soil moisture because of the presence of trapped air. Because of its direct bearing on water movement and water storage, it is important in any soil-water study to know the proportion of this pore space that is filled with water.

The proportion of detention pore space that is actually utilized by free water under natural conditions has never been determined to the complete satisfaction of all investigators. One reason has been that until recently there was no really good technique for determining total detention pore space (7). It is probable that some trapped air remains in the soil even under conditions of prolonged saturation by rainfall or snow melt. This prevents complete utilization of all the openings that would otherwise be available for the transmission and temporary storage of water. Estimates vary as to the percentage of total pore space thus occupied.

We determined that approximately 72 percent of the detention pore space was used by soil water when the samples were saturated.[8] The methods used in determining "calculated" pore space are described in the appendix.

[8] It should be remembered that these are laboratory determinations made on samples. Smith and Browning (11) found a lower degree of saturation in the field under natural rainfall, where entrapped air has less chance of escaping.

## Retention Storage

Average values were computed and grouped by percolation-rate classes the same as for detention storage. They are shown in tables 2 and 3.

Retention storage, like detention storage, is determined as a percentage of the oven-dried weight and is expressed on a volume basis.

Retention storage is greatly affected by the colloidal properties of the soil. The greater the colloidal content, the higher the retention-storage capacity. Since clay and organic matter are highly colloidal, both tend to increase the retention-storage capacity of soils. The medium-texture soils studied, most of which are silt loams, contain a high percentage of small particles and clay. Retention-storage capacities are more or less uniform.

## Transmission Rates And Transmission Capacities

Transmission rates are affected by soil and cover conditions in the same way as percolation rates. They are closely related to the volume of detention storage.

Transmission rates can be obtained by direct measurement or by calculation, provided certain values are known. These values are: The field moisture content, the percolation rate, the saturation capacity, and the transmission capacity. An attempt was made to obtain transmission rates by actual measurement on the samples, but it was not successful. (For details see appendix.) However, the data necessary for calculating transmission rates were obtained through this study. The transmission rates were calculated for the flood-control hydrologic evaluation that was based on this study. Transmission capacities, determined from the soil samples, were averaged for the various soil-cover complexes. These are shown in table 4.

It appears that water in the mineral B and C horizons saturates the soil 95 to 98 percent as it travels downward. On the other hand, in the $A_1$ layer of a mull humus, the soil is approximately 80 percent saturated by the first passage of water. In the H layer of a mor humus the figure drops to

Table 4.--Degree of saturation reached during transmission through the soil horizons

| Complex | Horizon | Land use | Well-drained or poorly drained horizon | Plots analyzed | Saturation obtained during transmission |
|---|---|---|---|---|---|
| | | | | Number | Percent |
| Forest mor | H | Ungrazed | Both | 9 | 70 |
| Forest mor | H | Grazed | Both | 1 | 76 |
| Forest mull | $A_1$ | Ungrazed | Both | 12 | 82 |
| Forest mull | $A_1$ | Grazed | Both | 9 | 91 |
| Forest | Lower A | Ungrazed | Well-drained | 20 | 91 |
| Forest | Lower A | Ungrazed | Poorly drained | 5 | 95 |
| Forest | Lower A | Grazed | Well-drained | 8 | 89 |
| Forest | Lower A | Grazed | Poorly drained | 1 | 98 |
| Open land | Plow layer | Row crops | Both | 4 | 96 |
| Open land | Plow layer | Close growing crops | Both | 6 | 93 |
| Open land | A or plow layer | Pasture | Both | 9 | 96 |
| All covers | Mid-horizon | All use | Well-drained | 32 | 97 |
| All covers | Mid-horizon | All use | Poorly drained | 11 | 98 |
| All covers | C[1] | All use | Well-drained | 12 | 95 |
| All covers | C | All use | Poorly drained | 19 | 98 |

[1] In the AB profiles this is actually an upper C value as all C samples were taken at 20 to 22 inches. In an AC profile this is a lower C value. In all plots the samples were taken at the same depth regardless of drainage and stage of profile maturity.

70 percent. This indicates a strong correlation between the volume and nature of detention storage and the degree of saturation attained during transmission. Where the detention pore spaces are large, numerous, and continuous, the pattern of wetting by the first downward movement of water is more erratic and shows less resemblance to a wet front.

## CORRELATIONS

A SECONDARY PURPOSE of the study was to attempt to identify and explain factors that affect percolation, detention storage, and retention storage. We analyzed the relationships between the soil-water values themselves and studied the influence of organic content and volume weight

Table 5.--Relationship between soil factors

| Correlations | Complex | Profile drainage | Regression equation[1] | Correlation coefficient |
|---|---|---|---|---|
| | | Class | | |
| Estimation of volume weight from organic content (percent by weight) | H horizon - Ungrazed forest | 1-2-3-4 | $VW = .49 + (-.0044)\ OC \pm .10$ | 0.73 |
| | $A_1$-$A_2$ horizon - Ungrazed forest | 1-2-3-4 | $VW = 1.15 + (-.022)\ OC \pm .10$ | .55 |
| | Mid-horizon - All forest | 1-2-3-4 | $VW = 1.51 + (-.089)\ OC \pm .12$ | .73 |
| | C horizon - Forest and open | 1-2-3-4 | $VW = 1.52 + (-.025)\ OC \pm .17$ | .89 |
| | $A_1$ horizon - Ungrazed forest | 1-2-3-4 | $VW = .88 + (-.015)\ OC \pm .11$ | .69 |
| | $A_1$ horizon - Grazed forest | 1-2-3-4 | $VW = 1.23 + (-.0184)\ OC \pm .20$ | .72 |
| | Mid-horizon - All forest | 1-2-3 | $VW = 1.50 + (-.088)\ OC \pm .13$ | .75 |
| | Mid-horizon - All forest | 4 | $VW = 1.52 + (-.077)\ OC \pm .10$ | .72 |
| Estimation of organic content (percent by weight) from volume weight | Whole woodland profile | 1-2-3-4 | $OC = \frac{6.270}{VW\ (1.53)} \pm 8.2$ | -- |
| Estimation of percolation rate from detention storage | Mid-horizon - Forest and open | 1-2-3-4 | $P = -4.66 + (1.36)\ DS \pm 10.9$ | .67 |
| | Mid-horizon - Forest and open | 1-2-3 | $P = 15.04 + (3.09)\ DS \pm 8.75$ | .69 |
| | Mid-horizon - Forest and open | 4 | $P = 4.26 + (1.31)\ DS \pm 11.1$ | .48 |
| Estimation of volume of detention storage from organic content (percent by weight) | Whole woodland profile | -- | $DS = 6.84 + (1.19)\ OC \pm 6.0$ | -- |
| | Mid-horizon - Forest and open | 1-2-3 | $DS = 7.64 + (1.05)\ OC \pm 4.1$ | .83 |
| | Mid-horizon - Forest and open | 4 | $DS = 4.83 + (.84)\ OC \pm 2.0$ | .82 |
| Estimation of volume of detention storage from volume weight | Whole woodland profile | 1-2-3-4 | $DS = \frac{12.06}{VW(.985)} \pm 6.0$ | -- |
| | Mid-horizon - Forest and open | 1-2-3-4 | $DS = 27.88 + (-14.01)\ VW \pm 3.5$ | -- |
| | Mid-horizon - Forest and open | 1-2-3 | $DS = 26.92 + (-12.84)\ VW \pm 3.7$ | .87 |
| | Mid-horizon - Forest and open | 4 | $DS = 20.82 + (-10.5)\ VW \pm 1.8$ | .92 |

[1] VW = volume weight; OC = organic content; DS = detention storage; P = percolation rate.

on these values. We hoped to find leads that would simplify similar work on other surveys: for example, relatively simple measurements that might be used in estimating the more complex soil-water relationships accurately enough for flood-control surveys.

The correlations that showed some promise, together with the resulting correlation coefficients and regression equations, are shown in table 5. The figures should be considered tentative, for an increase in the intensity of sampling might change the degrees of correlation indicated.

In addition to those correlations listed in the table, several others were tested; but a very low degree of correlation was found. These were: Percolation rate with volume weight, percolation rate with organic content, and retention storage with organic content.

We do not feel that the results of the correlation study are good enough for practical use in flood-control surveys. A few of the relationships shown were rather close when the data were stratified by cover, soil texture, horizon, and drainage classes. However, we feel that further testing is needed before even the best of these correlations should be used for purposes of estimating rates of water movement and storage capacities.

Other investigators (2, 4, 8, 10, 11) have studied and reported on most of the relationships shown in table 5. In general, the results of their efforts have been comparable to ours, that is, although they have indicated definite relationships between many of the factors measured, the influence of unmeasured factors has usually been important enough to invalidate the correlation for estimating purposes.

## SUMMARY AND CONCLUSIONS

IN A STUDY OF SOIL samples from representative parts of the Allegheny River watershed, the authors sought to find out how soil conditions and land use affect the movement and storage of water in the soil. Since the study was on a small scale, it is not possible to offer clear-cut answers to these questions. However, the findings indicate many impor-

tant factors that affect the soil's capacity to absorb and store water.

## Forest Soils

The major factors that affect soil-water relationships in forest lands are: (1) grazing, (2) drainage condition, and (3) humus type. The effects of forest type and past use (logging, for example) were not determined because not enough samples were available.

Livestock-grazing in woodlands affects the upper soil layers most. The organic content of the humus layer was reduced 32 percent by grazing, and its volume weight was increased approximately 80 percent. This reduced greatly the rate of water movement and the amount of detention storage in the upper horizons. The effect extended down through the lower A horizon. But the retention storage was not affected at any depth.

Drainage conditions had a great affect on water movement and storage, especially in the layers below the humus. Well-drained and imperfectly drained soils had similar water values through the A and B horizons. Poorly drained soils had lower percolation rates and lower detention-storage capacities in the comparable horizons. In the C horizon, imperfectly and poorly drained soils had similar water values, but had significantly lower percolation rates and detention-storage capacities than the well-drained soils. Lower percolation rates and detention-storage capacities were found wherever there was an inhibiting layer.

Water values differed significantly between the humus types (firm mull, other mulls, and mor) in ungrazed land. Between the H layer of mors and the $A_1$ layer of other mulls there were marked differences, especially in percolation rates. In the lower A layer the findings for mull and mor were similar. However, in a region of strongly podsolized soils this probably would not be true, because the lower A of the mors would have a smaller organic content than the lower A of the mulls. This relationship between humus types should be considered a tentative finding.

## Open-Land Soils

The major factors that affect soil-water relationships in open land are: (1) vegetative cover and (2) drainage condition. Although land-management practices were not studied individually, they are reflected in the quality of the vegetative cover.

The kind of vegetative cover had a distinct effect on the soil-water relationships in the plow layer or upper horizon. Soil where row crops were grown had the lowest percolation rates and detention-storage capacities. The highest rates were found in good pasture, close-growing crops, and hay. The B and C horizons were not affected.

Open-land soils were affected by drainage conditions the same way forest soils were affected.

In general, open-land soils had lower percolation rates and lower detention-storage capacities than forest soils in the upper horizon--regardless of vegetative cover. The differences were much smaller for the B horizons; and there were no differences for the C horizons. (These results were obtained without determining the effect of large roots on rates of water movement.) Detention storage, though much less variable, followed the same trend as percolation rates.

Retention storage was found to be practically the same in forest soils and open-land soils, for comparable horizons. This is attributed to the fact that most soils were loams and silt loams of residual origin. The addition of organic matter to such soils adds little to their relatively high field capacity.

## Correlations

Attempts to find correlations among these soil-water factors, which could be used as criteria for classifying soils in future flood-control surveys, were not fruitful. Some fairly close correlations were found between volume weights and organic content, and between volume of detention storage and volume weight. But they were not good enough to warrant their use in estimating rates of water movement and storage capacities. There is a possibility that better correlations might be obtained through more intensive sampling.

## Practical Application

This study shows that the physical soil improvements resulting from better land-management practices are greatest in the upper soil horizons. However, the effects of these improvements are not necessarily confined to these upper horizons. A physical improvement that increases the percolation rate and detention-storage capacity of any soil horizon increases the possibility of utilizing more fully the storage capacity of the underlying horizons.

The percolation rate and the detention-storage capacity of the A horizon determine the amount of water available for maintaining maximum percolation rates in the B horizon. Therefore, changes in the structure of the A horizon that increase percolation rates and detention-storage capacity will result in an increase in the amount of water available to the B horizon.

This relationship is particularly important in regard to flood-producing storms, in which precipitation intensities vary greatly. Periods of intense precipitation build up the volume of water in detention storage in the A horizon. Thus the greater the detention-storage capacity in the A horizon, the greater the volume available to maintain maximum percolation rates in the B horizon during periods when rainfall intensities fall below the maximum percolation rate in the B horizon.

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# APPENDIX

# DESCRIPTION OF SOIL PROFILE

THE DEVELOPMENT OF SOIL horizons is brought about largely through the action of rain water, which leaches materials from a surface layer and deposits most or all of them at a slightly greater depth. This process results in three major horizons.

A horizon--the leached zone.

B horizon--the zone of deposition.[9]

C horizon--the essentially unaltered parent material (3).

The A or surface horizon is characterized by numerous differences in structure, appearance, and chemical composition. These result from direct exposure to climatic conditions, the influence of vegetation, and the disturbances caused by man's use of the land. The greatest differences between woodland and open-land profiles are found in this horizon.

## A Horizon In Woodland Profiles

Woodland A horizons are divided into an upper A (humus layer) and a lower A. The humus layer is classified as either mull or mor.

1. Upper A layer. Classified as either mull or mor.

   A. If classified as a mull, "the humus layer consists of mixed organic and mineral matter. Transition to lower horizon not sharp" (7). It contains the following divisions:

      F layer: "Consists of a more or less decomposed forest litter still recognizable as to origin" (5).

[9] NO TRUE B HORIZON HAS DEVELOPED IN MANY OF THE SOILS OF THE ALLEGHENY WATERSHED. THESE ARE IMMATURE SOILS WITH THE A HORIZON RESTING DIRECTLY ON THE C HORIZON. IN THESE SOILS THE UPPER PART OF THE C HORIZON HAS UNDERGONE CONSIDERABLE MODIFICATION AND IS NOT STRICTLY COMPARABLE TO THE RELATIVELY UNAFFECTED C HORIZON FOUND BELOW THE B IN MATURE SOILS. THE GILPIN SOIL SERIES ARE AN EXAMPLE OF THE AC PROFILE SOILS.

$A_1$ layer: "Consists of a well mixed layer of organic matter and mineral soil."

B. If classified as a mor, the humus layer consists "of unincorporated organic material usually matted or compacted, or both, distinctly delineated from the mineral soil unless the latter has been blackened by the washing in of organic matter" (5). It contains the following divisions:

F layer: Same as in mull.

H layer: Consists principally of organic matter and usually is unrecognizable as to origin. The F and H layers make up the $A_0$ horizon.

2. Lower A layer.

A. Under a mull upper A horizon. There is less organic material in the lower A and the structure is more dense than in the $A_1$ above it. This layer may be integrated so gradually into the $A_1$ that no line of demarcation is visible.

B. Under a mor upper A horizon. The lower A layer under a mor humus is the $A_2$ layer. It is "a light-colored horizon, often representing the zone of maximum leaching" (3). In a strongly podsolized soil this layer is often white, sandy, and low in organic content.

## A Horizon In Open-Land Profiles

The purely organic layers are missing in most of the open-land soils. The top or A layer has been disturbed by cultivation and a more or less artificial horizon has been created, which extends to plow depth. This artificial layer is composed of a mixture of the A and B horizons. Exceptions to this condition occur in these localities where the topsoil is deeper than the average plow depth and where open-land conditions have been maintained without plowing. Many pasture areas are examples of the latter.

## CHARACTERISTICS OF LIGHT-TEXTURE SOILS

INSUFFICIENT SAMPLING in the light-texture group prevented a thorough analysis of these soils. However, it was possible to draw the following tentative conclusions:

1. Differences in soil-water relationships in the two texture groups are not significant in the upper part of the A horizon where the predominant influences are organic matter and land use.

2. The lower A horizon and the B horizon of the light-texture soils have a higher percolation rate, a higher detention-storage capacity, and a lower retention-storage capacity than the medium-texture soils.

3. The C horizon (20 inches and deeper) of both texture groups appears to be essentially similar in rates of water movement and storage capacities.

## CALCULATED PORE SPACE

TOTAL CALCULATED PORE space is determined by the use of the following equation:

$$\text{Total porosity} = 1.00 - \frac{\text{volume weight}}{\text{specific gravity}}$$

To illustrate, we have a sample with a volume weight of 1.32 and a specific gravity of 2.60.

$$\text{Total porosity} = 1.00 - \frac{1.32}{2.60} = 1.00 - 0.508 = 0.492$$

Total pore space is 49.2 percent of the sample. If the measured field capacity is 40.0 percent then:

49.2 - 40.0 = 9.2 percent calculated possible detention storage. However, by the method used in our study, we measured 6.9 percent detention storage.

$\frac{6.9}{9.2}$ = 75 percent of the calculated possible detention storage capacity is utilized by soil water.

In the calculation of pore space the volume weights were obtained from the samples but the specific gravities were determined mathematically. Appropriate specific-gravity values were assigned to the organic and mineral portions of the sample. The specific gravity of mineral soil is generally considered (7) to be 2.65 and that of organic matter to vary between 1.2 and 1.7. In this study 1.5 was used.

To illustrate the calculation of specific gravity for a given sample:

$$\text{S.g. of sample} = \frac{1}{\dfrac{\text{\% org. cont. by wt.}}{\text{S.g. of org. matter}} \quad \dfrac{\text{\% mineral cont. by wt.}}{\text{S.g. of mineral soil}}}$$

Assume an organic content of 10 percent.

$$\text{S.g. of sample} = \frac{1}{\dfrac{0.10}{1.5} \quad \dfrac{0.90}{2.65}} = \frac{1}{0.067 \quad 0.340} = \frac{1.000}{0.407}$$

Specific gravity = 2.46.

Since the relationship between the specific gravity of the sample and its present organic content is mathematical, it can be plotted easily.

It must be remembered that in these calculations the specific gravity of organic matter was taken as 1.5. If 1.2 (generally considered as approximately the lower limit) had been used, the percentage of calculated pore space that was utilized by water would have been higher for the highly organic samples. Thus the higher the organic content, the greater the chance for error in these calculations.

## TRANSMISSION RATES

TRANSMISSION RATES FOR ANY one soil-cover complex appear to depend to a great extent on the moisture content of the sample to which water is applied, that is, the moisture content of the sample in percentage of either its retention-storage capacity or its saturation capacity.

This conclusion came as a result of our attempt to measure transmission rates directly on samples at field moisture content. A trial analysis of the data showed only

a weak relationship between transmission rates and the soil-cover complexes that were significant in percolation-rate grouping. To determine the cause of this, the individual field moisture contents of the samples from one group, well-drained mid-horizons, were expressed as a percentage of retention storage. When their transmission rates were plotted over these percentages there was an obvious relationship--the higher the percentages the faster the transmission rate.

The following test was made to check the validity of this relationship: Transmission rates were run on several samples at field moisture content. In all cases this field moisture content was below retention-storage capacity. After this application of water, the nearly saturated samples were drained down to retention-storage capacity on the tension table. Then transmission rates were determined again. The last set of transmission rates (those determined on the samples at retention-storage capacity) were higher, thus substantiating the relationship shown in the trial analysis.

Fortunately, transmission rates can be computed. The following example illustrates the method: The horizon in question has a percolation rate of 5.0 inches per hour; field moisture content is at 30 percent; saturation capacity is 50 percent; the horizon is saturated 93 percent during transmission--

$$0.93 \times 0.50 = .465$$

$$0.465 - 0.30 = .165$$

5.0 inches per hour percolation rate $\div$ 0.165 = 30.3 vertical inches per hour transmission rate.

When the soil is saturated, transmission rates are virtually infinite. A drop of water added to the top of the soil sample would cause a drop to appear at the bottom almost instantly. Because of this, the formula for computing transmission rates can be applied only when soil moisture content is below saturation.

# SAMPLING ACCURACY

The greatest standard errors were found in the percolation rates. In other words, if enough samples are taken to obtain a set goal of accuracy for percolation rates, these samples will be more than sufficient to obtain the same degree of accuracy for detention and retention storage. Standard errors expressed in "percent accuracy" are shown for percolation rates in table 6, for detention storage in table 7, and for retention storage in table 8.

Since satisfactory estimates of sampling error were not available in advance of this study, the intensity of sampling was based upon estimates of the expected variability. Future sampling should be aimed at obtaining a given degree of accuracy. With data similar to those obtained from this analysis, the number of plots necessary to obtain standard errors of 10 and 20 percent has been determined by complexes. It is shown in tables 6 to 8. These data can be used as guides to the intensity of sampling in future work.

However, in an extensive sampling job such as this, there are other factors to be considered besides a high degree of accuracy. The time and cost involved must be weighed against the value of increasing the accuracy of the data. An accuracy standard considered inadequate in pure research may be highly satisfactory for survey purposes.

In the analysis of the percolation rates a comparison was made of the degree of accuracy between plots and within plots. This was done so that in future work, with data of equal variability, the number of samples and plots necessary to obtain a given degree of accuracy could be more closely estimated. Table 9 shows the numbers of samples (by horizons) that provide the best balance of accuracy between plots and within plots.

Table 6.--Standard errors of percolation rates and estimated number of plots required for various standards of accuracy

F O R E S T   L A N D

| Complex | Profile drainage[1] | Present data | | | Plots required for sampling error of-- | |
|---|---|---|---|---|---|---|
| | | Accuracy | Actual rate | Plots | 10% | 20% |
| | Class | Per-cent | Inches per hour | Number | Number | Number |
| H ungrazed (mors) | 1-2-3-4 | 10 | 236.0 ± 23 | 9 | 9 | 3 |
| $A_1$ ungrazed (other mulls) | 1-2-3-4 | 21 | 132.0 ± 28 | 12 | 53 | 13 |
| $A_1$ ungrazed (firm mull) | 1-2-3-4 | -- | 62.7 | 1 | -- | -- |
| $A_1$ grazed (mulls) | 1-2-3-4 | 40 | 30.2 ± 12 | 9 | 158 | 39 |
| $A_2$ ungrazed (mors and other mulls) | 1-2-3<br>4 | 16<br>45 | 17.0 ± 2.8<br>10.9 ± 4.9 | 21<br>5 | 60<br>100 | 15<br>25 |
| $A_2$ ungrazed (firm mull) | 1-2-3 | -- | 7.8 | 1 | -- | -- |
| $A_2$ grazed (mulls and mors) | 1-2-3<br>4 | 69<br>-- | 13.1 ± 9.1<br>3.6 + | 7<br>1 | 78<br>-- | 20<br>-- |
| Mid-horizon all land-use classes[2] | 1-2-3<br>4 | 17<br>75 | 4.7 ± .78<br>2.7 ± 2.02 | 48<br>7 | 136<br>432 | 34<br>108 |
| C all land-use classes[3] | 1<br>3-4 | 14<br>27 | 2.1 ± .3<br>.6 ± .16 | 12<br>24 | 35<br>238 | 9<br>59 |
| | | O P E N   L A N D | | | | |
| AB or AC close-growing crop[4] | 1-2-3-4 | 22 | 21.7 ± 4.8 | 6 | 31 | 8 |
| AB or AC good pasture | 1-2-3 | 67 | 18.5 ± 12.4 | 3 | 115 | 29 |
| AB or AC poor pasture | 1-2-3<br>4 | 46<br>-- | 12.8 ± 5.9<br>2.5 | 5<br>1 | 82<br>-- | 21<br>-- |
| AB or AC hay | 1-2-3<br>4 | 22<br>74 | 21.7 ± 4.8<br>7.7 ± 5.7 | 6<br>2 | 31<br>115 | 8<br>29 |
| AB or AC row crop | 1-2-3<br>4 | 30<br>-- | 6.7 ± 2.0<br>2.9 | 2<br>1 | 20<br>-- | 5<br>-- |
| AB or AC abandoned pasture[5] | 1-2-3-4 | 46 | 12.8 ± 5.9 | 6 | 31 | 8 |
| Mid-horizon all land-use classes[2] | 1-2-3<br>4 | 17<br>33 | 4.7 ± .78<br>.7 ± .23 | 48<br>6 | 136<br>161 | 34<br>40 |
| C all land-use classes[3] | 1<br>3-4 | 14<br>27 | 2.1 ± .3<br>.6 ± .16 | 12<br>24 | 35<br>238 | 9<br>59 |

[1] 1, Well-drained deep; 2, Well-drained shallow; 3, Imperfectly drained; 4, Poorly drained.

[2] The Fisher t-test showed no significant difference between 1-2-3 for open land and 1-2-3 for forest horizons and these data were combined and weighted to give the above results. Drainage class 4 showed a significant difference.

[3] The Fisher t-test showed no significant difference between well-drained deep soils in forest and open-land plots and the two land-use classes were combined. Likewise imperfectly and poorly drained plots of both forest and open land were combined.

[4] The Fisher t-test showed no significant difference between the data for hay (1-2-3) and close-growing crop (1-2-3-4) and the data for the two land-use classes were combined and weighted.

[5] The Fisher t-test showed no significant difference between abandoned pasture (1-2-3-4) and poor pasture (1-2-3) and the two were grouped to give the above results.

Table 7.--Standard errors of detention storage and estimated number of plots required for various standards of accuracy

FOREST LAND

| Complex | Profile drainage | Present data | | | Plots required for sampling error of-- | |
|---|---|---|---|---|---|---|
| | | Accuracy | Actual storage | Plots | 10% | 20% |
| | Class | Per-cent | Percent by volume | Number | Number | Number |
| H ungrazed (mors) | 1-2-3-4 | 5.6 | 33.8 ± 1.9 | 9 | 3 | 1 |
| $A_1$ ungrazed (other mulls) | 1-2-3-4 | 9.8 | 23.4 ± 2.3 | 12 | 12 | 3 |
| $A_1$ ungrazed (firm mull) | 1-2-3-4 | -- | 27.3 | 1 | -- | -- |
| $A_1$ grazed (mulls) | 1-2-3-4 | 17.5 | 12.6 ± 2.2 | 9 | 27 | 7 |
| $A_2$ ungrazed (mors and other mulls) | 1-2-3<br>4 | 8.8<br>13.9 | 14.8 ± 1.3<br>10.8 ± 1.5 | 21<br>5 | 16<br>10 | 4<br>3 |
| $A_2$ ungrazed (firm mull) | 1-2-3 | -- | 14.5 | 1 | -- | -- |
| $A_2$ grazed (mulls and mors) | 1-2-3<br>4 | 8.0<br>-- | 13.7 ± 1.1<br>5.1 | 8<br>1 | 5<br>-- | 2<br>-- |
| Mid-horizon all land-use classes[1] | 1-2-3<br>4 | 6.0<br>10.5 | 9.6 ± .57<br>6.0 ± .63 | 47<br>7 | 17<br>8 | 5<br>2 |
| C all land-use classes[1] | 1<br>3-4 | 4.9<br>11.2 | 10.6 ± .52<br>5.7 ± .64 | 12<br>24 | 3<br>30 | 1<br>8 |
| OPEN LAND | | | | | | |
| AB or AC close-growing crop[2] | 1-2-3-4 | 12.6 | 12.7 ± 1.6 | 6 | 10 | 3 |
| AB or AC good pasture | 1-2-3 | 14.2 | 7.7 ± 1.1 | 3 | 6 | 2 |
| AB or AC poor pasture | 1-2-3<br>4 | 18.2<br>-- | 11.0 ± 2.0<br>4.7 | 5<br>1 | 16<br>-- | 4<br>-- |
| AB or AC hay | 1-2-3<br>4 | 12.6<br>51.1 | 12.7 ± 1.6<br>9.2 ± 4.7 | 6<br>2 | 10<br>54 | 3<br>14 |
| AB or AC row crop | 1-2-3<br>4 | 14.6<br>-- | 10.3 ± 1.5<br>8.4 | 2<br>1 | 4<br>-- | 1<br>-- |
| AB or AC abandoned pasture[3] | 1-2-3-4 | 18.2 | 11.0 ± 2.0 | 5 | 16 | 4 |
| Mid-horizon all land-use classes[4] | 1-2-3<br>4 | 6.0<br>13.0 | 9.6 ± .57<br>5.8 ± .75 | 47<br>6 | 17<br>10 | 5<br>3 |
| C all land-use classes[4] | 1<br>3-4 | 4.9<br>11.2 | 10.6 ± .52<br>5.7 ± .64 | 12<br>24 | 3<br>30 | 1<br>8 |

[1] Combined for same classes as percolation rates. See table 2 for forest-land values separate.

[2] See footnote 2, table 6.

[3] See footnote 3, table 6.

[4] Combined for same classes as percolation rates. See table 3 for open-land values.

Table 8.--Standard errors of retention storage and estimated number of plots required for various standards of accuracy

FOREST LAND

| Complex | Profile drainage | Present data | | | Plots required for sampling error of-- | |
|---|---|---|---|---|---|---|
| | | Accuracy | Actual storage | Plots | 10% | 20% |
| | Class | Per-cent | Percent by volume | Number | Number | Number |
| H ungrazed (mor) | 1-2-3-4 | 5.0 | 37.8 ± 1.9 | 8 | 2 | 1 |
| $A_1$ ungrazed (other mulls) | 1-2-3-4 | 7.5 | 41.1 ± 3.1 | 12 | 7 | 2 |
| $A_1$ ungrazed (firm mull) | 1-2-3-4 | -- | 32.6 | 1 | -- | -- |
| $A_1$ grazed (mulls) | 1-2-3-4 | 8.2 | 41.4 ± 3.4 | 9 | 6 | 2 |
| $A_2$ ungrazed (mors and other mulls) | 1-2-3 | 3.8 | 36.8 ± 1.4 | 21 | 3 | 1 |
| | 4 | 4.5 | 40.4 ± 1.8 | 5 | 1 | 1 |
| $A_2$ ungrazed (firm mull) | 1-2-3 | -- | 31.7 | 1 | -- | -- |
| $A_2$ grazed (mulls and mors) | 1-2-3 | 3.7 | 38.3 ± 1.4 | 8 | 1 | 1 |
| | 4 | -- | 40.8 | 1 | -- | -- |
| Mid-horizon all land-use classes | 1-2-3 | 2.2 | 36.3 ± .8 | 48 | 3 | 1 |
| | 4 | 3.4 | 37.8 ± 1.3 | 7 | 1 | 1 |
| C all land-use classes | 1 | 2.5 | 35.4 ± .9 | 12 | 1 | 1 |
| | 3-4 | 2.2 | 35.7 ± .8 | 24 | 2 | 1 |
| OPEN LAND | | | | | | |
| AB or AC close-growing crop | 1-2-3-4 | 5.2 | 38.3 ± 2.0 | 6 | 2 | 1 |
| AB or AC good pasture | 1-2-3 | 7.9 | 43.1 ± 3.4 | 3 | 2 | 1 |
| AB or AC poor pasture | 1-2-3 | 4.4 | 38.3 ± 1.7 | 5 | 1 | 1 |
| | 4 | -- | 50.5 | 1 | -- | -- |
| AB or AC hay | 1-2-3 | 5.2 | 38.3 ± 2.0 | 6 | 2 | 1 |
| | 4 | 9.1 | 42.7 ± 3.9 | 2 | 2 | 1 |
| AB or AC row crop | 1-2-3 | 18.3 | 35.5 ± 6.5 | 2 | 7 | 2 |
| | 4 | -- | 51.0 | 1 | -- | -- |
| AB or AC abandoned pasture | 1-2 3-4 | 4.4 | 38.3 ± 1.7 | 5 | 1 | 1 |
| Mid-horizon all land-use classes | 1-2-3 | 2.1 | 36.7 ± .8 | 48 | 3 | 1 |
| | 4 | 3.6 | 36.3 ± 1.3 | 6 | 1 | 1 |
| C all land-use classes | 1 | 2.5 | 35.4 ± .9 | 12 | 1 | 1 |
| | 3-4 | 2.2 | 35.7 ± .8 | 24 | 2 | 1 |

Table 9.--Proposed intensity of sampling within plots

| Cover complexes | Number of samples to be taken at each plot | | | | | |
|---|---|---|---|---|---|---|
| | H | $A_1$ | AB or AC | $A_2$ or $A_3$ | Mid-horizon | C |
| I. Forest land | | | | | | |
| Ungrazed | (1/) | 4 | -- | 5 | 5 | 3 |
| Grazed | (1/) | 5 | -- | 5 | 5 | 3 |
| II. Open land | | | | | | |
| All covers | -- | -- | 4 | -- | 5 | 3 |

[1] Since the percolation rate in the H is so high that it exceeds rainfall intensities that can reasonably be expected, there will be no need to take additional H samples in the Northeast.


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